Abstract

The early decades of sound recording are a period of rapid change in both recording technology and performance practice. Primitive recording equipment, minimal documentation and musical pitch varying by time and location make it difficult for archivists to know the proper playback stylus size and playback speed. Using four very large data sets of both pristine and worn media, combined with a highly consistent selection methodology, this study investigates the level of accuracy attainable when selecting stylus size and determining playback speed. The analysis shows it is possible to determine, with high certainty, the correct playback stylus size per record label during this period of early sound recording. The analysis then shows that the distribution of pitch follows a Gaussian distribution of randomness; meaning, it is not possible to know with certainty the proper playback speed. Commentary discusses the cultural environment of the early recording era and the implications for archival practice today.

Historical Context

Every field of critical inquiry that engages with the past inevitably must address questions that are very difficult, if not impossible to answer. What color were dinosaurs? What was before the Big Bang? On what day was Henry V born? Was Thomas Jefferson a good violinist or a bad violinist? Aristotle wrote, “Everyone desires to know”. Our desire for knowledge and certainty propels human inquiry, especially when that inquiry involves the roots of our identity. The insatiable need to know leads us to uncover the previously unknown, even though the answer, if ultimately found, may prove dissatisfying, either because it challenges our assumptions, or is simply not very interesting after all. Furthermore, we must embrace and apply new information and knowledge appropriately; and accept when we do not and may not ever know certain information, and accept that our actions are based on assumptions and opinion, rather than facts, however well founded.

On the front of the Stephansdom Cathedral in Vienna are 2 iron bars, each about a meter long, one about a hands’ width longer than the other. Installed in the Middle Ages, these were the official Viennese measurements of a yard for use by local and traveling merchants for general commerce in the city. There was a measure for linen, and a separate measure for drapery. A traveling merchant adjusted his practice to the local standards. For hundreds of years, this was the state of standardization in the world.

The early part of the 20th century was a time of great changes. The Industrial Revolution brought prosperity to a new middle class. New modes of transportation brought far-flung parts of the world into contact. As manufacturing expanded with the introduction of interchangeable parts, the need for standards in weights and measures became apparent. Likewise, manufacturers soon found ways to create

entertainment goods for the new mass market.

At the same time, many technologies were new and poorly understood. Electricity was lighting homes before anyone understood grounding. Electric motors and microphones[1] were crude. Their use in sound recordings was limited prior to the development of electrical recordings ca. 1923. Speed was hard to measure and regulate[2]. There was no understanding of, much less the means to measure, distortion. There were no definitions for frequency response and level, speed fluctuation, gain, or linearity.

Standards as we understand and use them today, were taking root in the early decades of the 20th century. As the formerly isolated peoples of the world began to interact more frequently, they shared their goods and cultures. To work together they needed to adapt or adopt the things they wished to share. For musicians to play together they needed a common pitch and tuning system. Between 1895 and 1910 there were three international meetings to define the frequency of the A above Middle C. At those meetings the standard rose from 430 to 435, then to 440Hz[3]. It takes a long time for a standard like this to become widely practiced. Musicians, like people in all walks of life, can be slow to adopt change. More practically, instruments are not replaced very frequently. Church organs and string instruments may last centuries[4]. The physical dimensions of an instrument affect its characteristic pitch.

Into this brave new world of evolving standards, fluid pitch, and new inventions arrives recorded sound. One might reasonable say the early technicians and recording engineers were "making it up as they went along". For some experimenters we have lab notes that document the goals, methods, and discoveries of their work[5]. For some recording sessions, the recording staff kept notes. Thomas

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[1] The microphone was developed independently by Emile Berliner and David Edward Hughes in the 1870s. It is one of the fundamental precursors of Alexander Graham Bells'

[2] It's one thing to make an electric motor go 'round. It another thing to make it go 'round at a consistent speed, an imperative for sound recordings.

[3] The issue of pitch would remain important. When the new International Standards Organization (ISO) was formed in 1955, one of their first tasks was to adopt a uniform frequency of A=440 as ISO 16. This is where we get the expression "Standard Pitch", by which we mean A=440.

[4] Woodwind and brass instruments rarely last more than a generation. Professional musicians may "blow out" an instrument in 5-10 years. This idea was put to me by Jay Krush, founding member of Chestnut Brass Company, an ensemble that specializes in playing early brass instruments. Most of the historic instruments they've been able to collect are real dogs. "The good ones were played until they died. The ones that survive were owned by amateurs who rarely played them, then threw them in a closet until their grandchildren found them."

[5] An excellent summary of work by the Edison staff: *STYLUS SHAPES and SIZES: Preliminary Comments on Historical Edison Cylinder Styli*, by Bill Klinger, Chair of the ARSC Cylinder Committee.

Edison left behind some very detailed technical drawings. Unfortunately, just as they were "making it up as they went along", they didn't really know what information might be worthwhile to keep - either for the benefit of their developing profession, or for future researchers.

Despite the many limitations of weight driven lathes and large acoustic horns, and the uncertainties about practices in the early decades, we nonetheless have documents of the cultural record that do not exist from earlier times. Audiovisual records are what distinguish the cultural record of the 20th century. This is what drives our curiosity to understand these media. We gain both a better understanding of our history during this important period of change, and as audiovisual archivists, an appreciation for the roots of our profession.

The Problem

There are serious challenges to determining the correct way to reproduce these recordings. At what speed was the lathe turning on the day this particular recording was made? What pitch did the musicians tune to? How accurately regulated was the speed of the lathe? Did the musicians re-tune between takes? Were the musicians from different traditions and choose a compromise pitch for the recording date?[6]

As we can see, there are many contextual problems to determining "what is the correct speed" of an acoustic 78rpm disc. Lacking strong documentation from a period of general uncertainty, we are forced to work with the recording engineer's final product, that is the discs themselves. The overwhelming majority of the discs in existence are heavily worn from many years of use and enjoyment. This wear means our work in reproduction, especially stylus selection, must take this deterioration into account in the data we gather. Just as archaeologists must interpret fossils and astronomers must compensate for the affect of the Earth's atmosphere when peering into the heavens, record wear obscures our data[7].

[6] The author is grateful to Clara Blood, DMA, for furnishing this fascinating discussion on this topic as viewed from a different vantage: Oboists as keeper of orchestral pitch. http://www.oboeclassics.com/Burgess.htm
[7] This assumption regarding the impact of record wear is brought into question later in this paper.

The Digitization Process

The playback and digitization process followed the widely adopted best practices of the trade:

- Hand-delivered from home institutions
- Cleaned with Keith Monks Record Cleaning Machine (distilled water)
- Pictures of the label and matrix (Nikon D810 at 400ppi TIFF)
- Technics SP-15 Turntable fitted with needles by Expert Stylus
- 4 KAB preamps
- 8 Channel PrismSound ADA-8XR (96kHz/24bit)
- Pitch detection
- Trim and render derivatives for National Jukebox[8]
- Harvest and store AES-57 metadata

Figure 1

Figure 1. This is the playback system built for this work. By mounting 4 tone arms, 4 different styli can be reproducing at the same time. The engineer can compare, in real time, the sound of each stylus and rapidly switch between them. Compared to the traditional method of manually changing the stylus, then

[8] All the work for the Library of Congress is destined for this site: http://www.loc.gov/jukebox/

replacing with another, then changing back, etc., there is no need to remember what one stylus sounded like. With the push a button the operator can compare, not 2 but 4, different styli rapidly.

The Data

The core sources[9] for this study have several attributes that make the data especially relevant:

- The sample sets are large: more than 9,000 disc sides.
- The data include international sources.
- A period of approximately 20 years of early recording practice is covered.
- All work was performed to the same specifications.
- All work was performed with the same equipment.
- All work was performed by the same engineer.

These are the four data sets used in this study:

• Victor Talking Machine Company
The Victor discs are the stuff collectors, engineers and historians dream of. They are in pristine condition, beautifully preserved at the Eldridge Johnson Museum. Most of the rare and international titles in this study are in this collection.

• Edison Diamond Discs
These are factory originals, also in pristine condition ('reference discs' they might be called), under the care of Gerald Fabris at the Edison National Historic Park. This data set includes multiple takes of the same selection.

• OKeh Records
Unlike the Victor and Edison discs, the OKeh disc collection was assembled from discs that had circulated in the wild. They had been bought in stores, played, enjoyed, and handled under a random set of circumstances. They are far more representative of the samples available to most studies. They are holdings of the Library of Congress, at the Packard Campus of the National Audio-Visual Conservation Center, in Culpeper, VA.

• Mick Moloney Collection of Irish-American Music and Popular Culture

[9] The data for this paper was collected from two contracts performed for the Library of Congress and another contract for New York University. It is important to note that none of these contracts required the acquisition of data *for* this study. Flaws in the methods of data gathering and analysis are evident throughout. However, the findings are extremely clear, more than overcoming these flaws. Efforts are taken throughout the paper to point out where a more disciplined approach could have been followed, and how better method may or may not have produced different results. The raw data are available at www.georgeblood.com.

This New York University Collection is included to represent the general population, as a control and for comparison[10]. Insofar as the focus of the collection is Irish music, there is no preference for a given label. Like the OKeh Records samples, these are discs that had circulated in the wild.

The highly uniform digitization process allows us to investigate variation within each collection and between the four sets, and to explore the sources of those variations.

The findings from each data set are first presented separately.

PART 1, STYLUS SIZE

Victor Talking Machine Company

The Victor recordings data represents 3,500 sides. When the Victor Talking Machine Company operated in Camden, NJ, they sent copies of each title to the Free Library of Philadelphia. Like all libraries, only about 2% of their holdings circulate, and the sound recordings followed this pattern. When the Library chose to de-accession their analog sound recordings, the Victor discs moved to the Eldridge Johnson Museum, run by the Delaware Department of Parks and Recreation. This is an enormous collection of rarely played discs.

Most of the recordings at the Eldridge Johnson Museum are widely distributed. The selection of discs to digitize was led by Samuel Brylawski, Editor/Project Manager of the Encyclopedic Discography of Victor Recordings/American Discography Project at the University of California at Santa Barbara, someone who we can reasonably assume to know a thing or two about the Victor catalog. This project selected very rare recordings of Eastern Europeana, South American, and ethnic recordings. Therefore, we have an international distribution over a range of two decades, making our sample set both large, and widely representative.

[10] It is important to point out the data from the Moloney Collection used in this study includes both acoustic and electrical recordings. Therefore, it is far from perfect for comparison with the Victor, Edison and OKeh data.

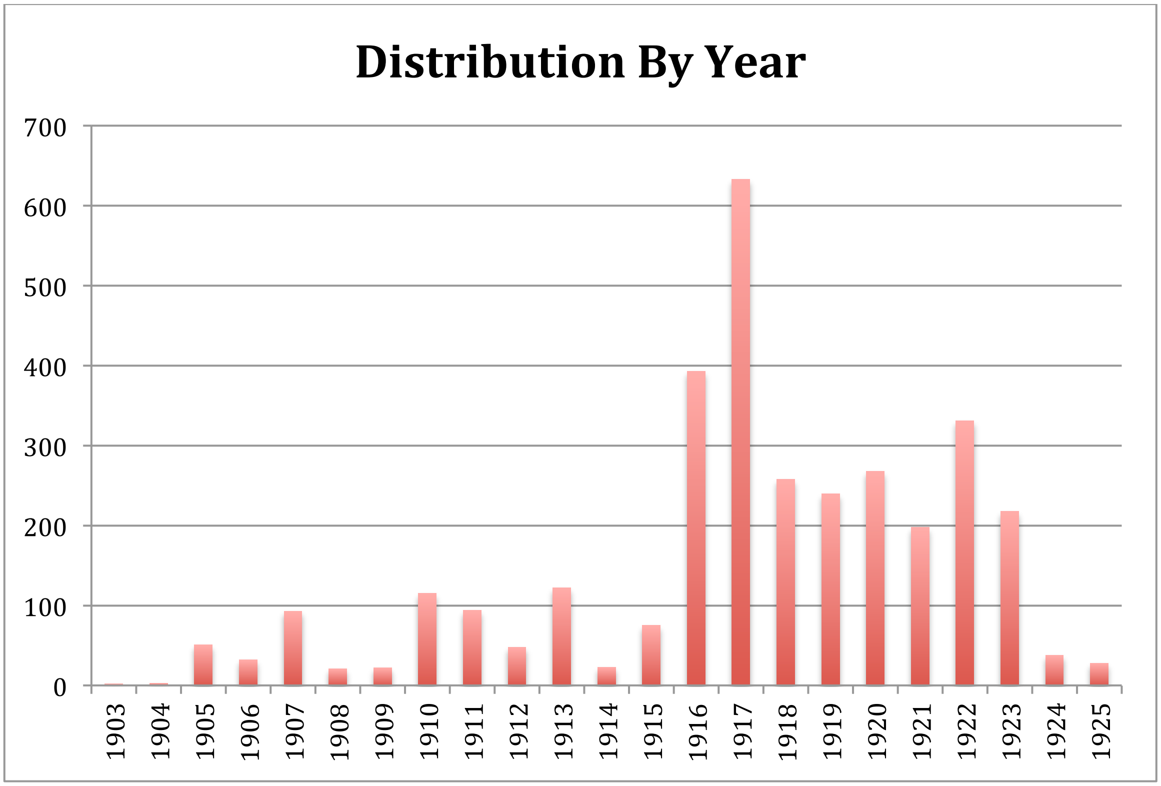

Figure 2

Figure 2 illustrates that within our sample set, some time periods are better represented than others.

This sample bias is the result of selections focused on rare ethnic titles. While this gives the sample a highly desirable international distribution, the results are less evenly representative of the time period. A more carefully designed study might have added samples where the distribution has a low number of titles. However, the data will show this would not have had a significant impact on the results.

During this period there is great variation of performance practice by region. This is very important for the investigation of speed and pitch, which will be discussed in the second half of this paper. The sample set has the advantage that the recordings were made by teams from the same label.

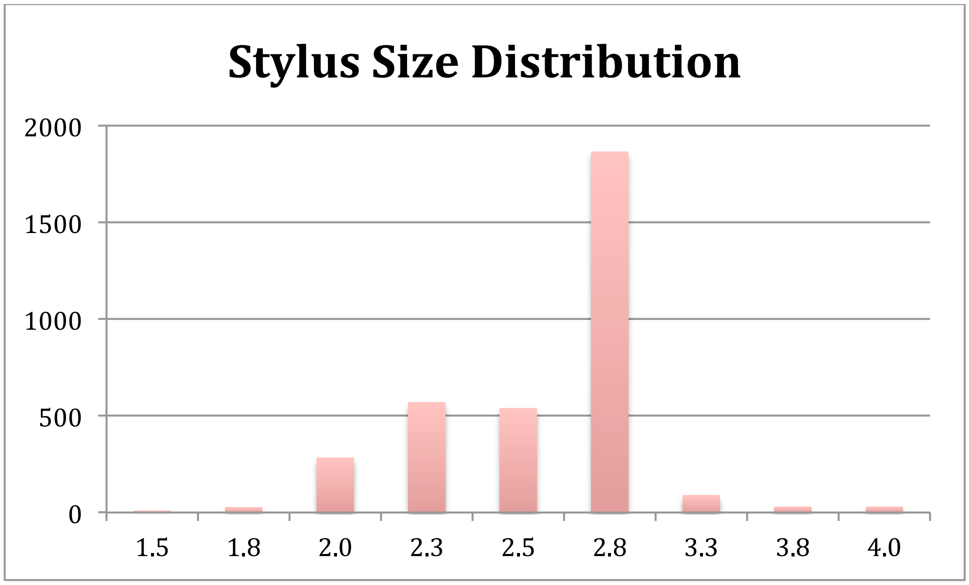

Figure 3[11]

Data from the Victor discs show this remarkably clear finding. One stylus size, 2.8mil, was chosen for more than half the Victor sides digitized. The data were next examined for an explanation of the secondary strengths at 2.0, 2.3 and 2.5mil.

The data were analyzed to determine whether the distribution of sizes matched the distribution over time. Higher numbers of sides are expected in the subsets at 1916-1917 and later because there are more data points to begin with (cf. Figure 2).

[11] Please pay attention to the scaling on the left side of these charts. Some times it is scaled for maximum resolution, and other times scaled to a fixed unit to facilitate comparison between charts.

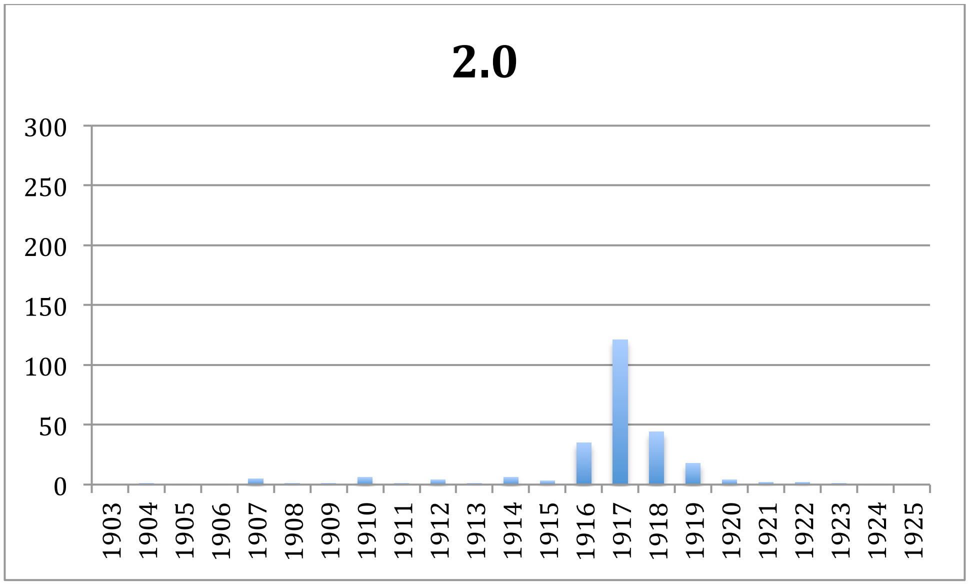

Figure 4a

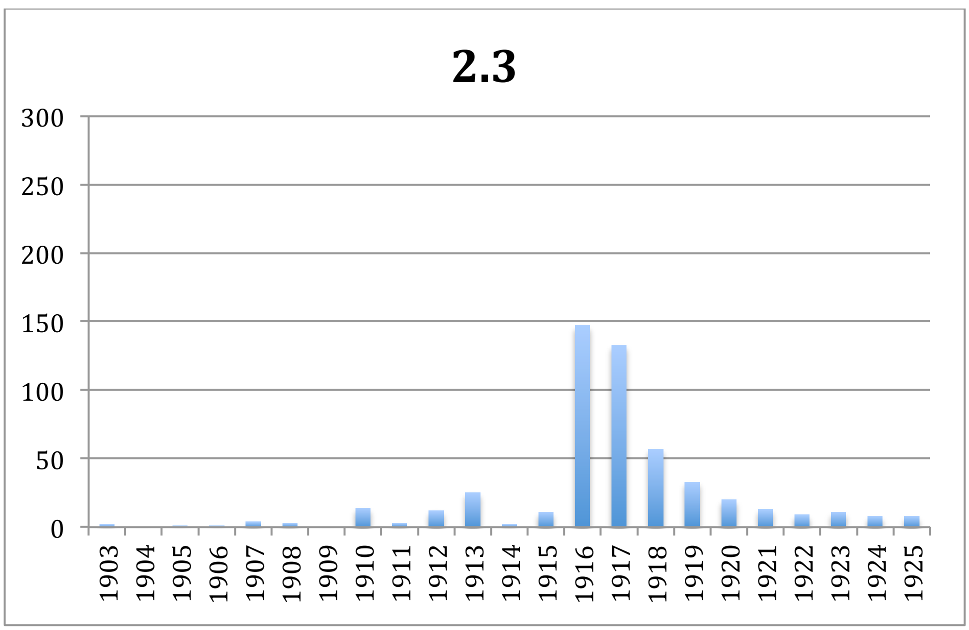

Figure 4b

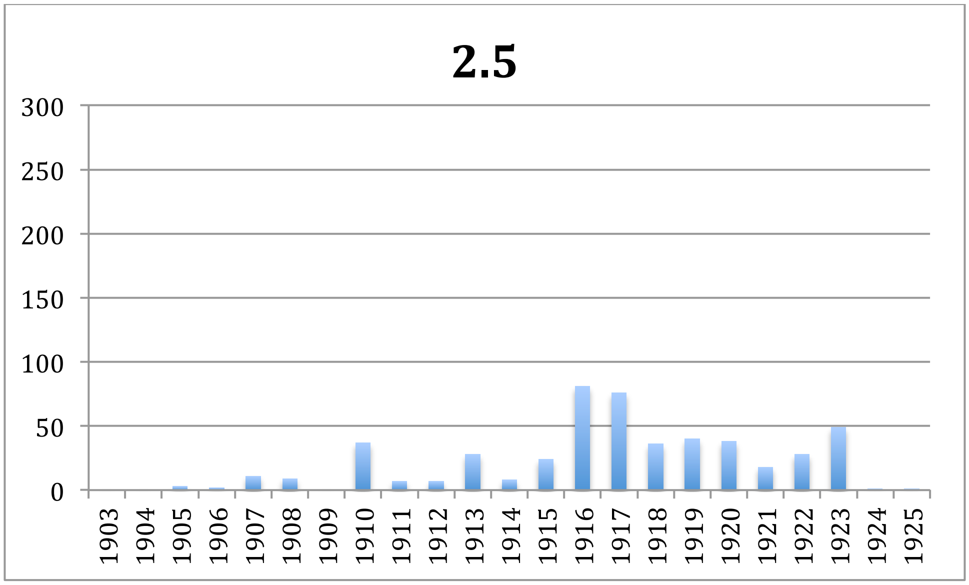

Figure 4c

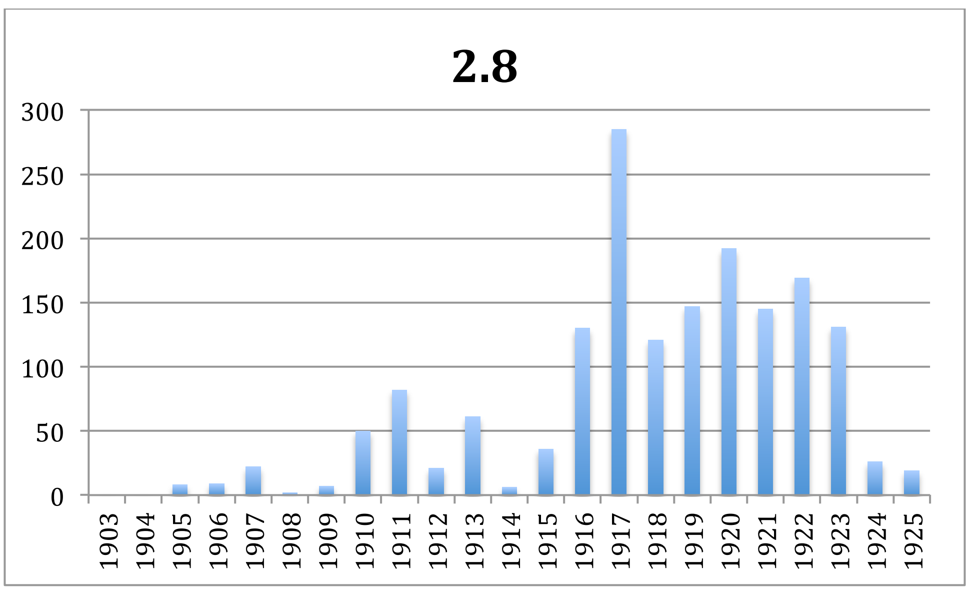

Figure 4d

And indeed that is what we see in the data. The peaks in the stylus size subsets mirror the peaks in the aggregate data. Further, no trend appears in the data. The data do not show size A being used in the early 19-teens, then a few years later, toward the 1920's, a different size is dominant, and so on. The distribution of 2.0, 2.3 and 2.5 is fairly even, with significantly more 2.8 across all time periods.

The data were next analyzed by the recording location. Just as with the distribution of the stylus size by catalog number, we find the same pattern: all locations dominated by 2.8 mil, followed by smaller sizes, as shown in Figure 5a-5d.

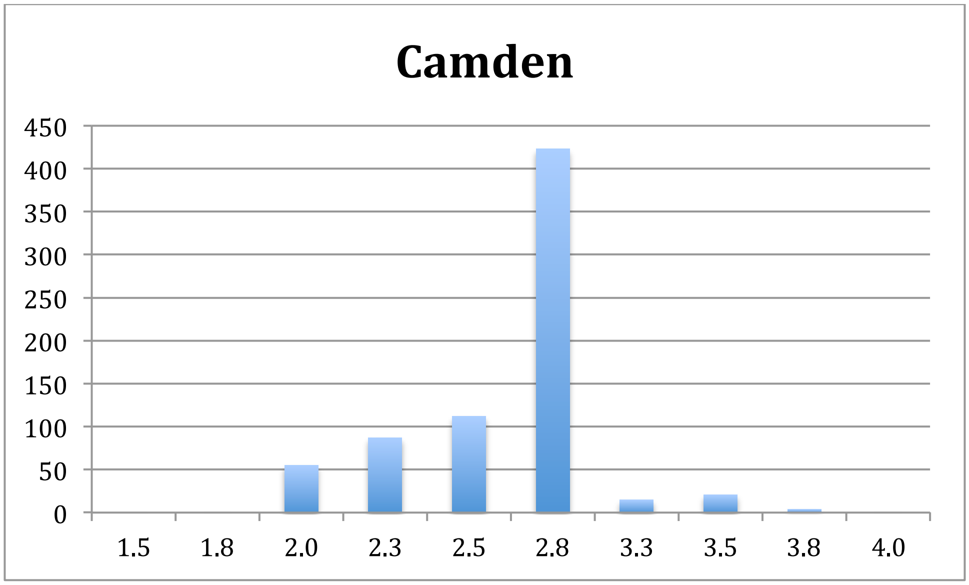

Figure 5a

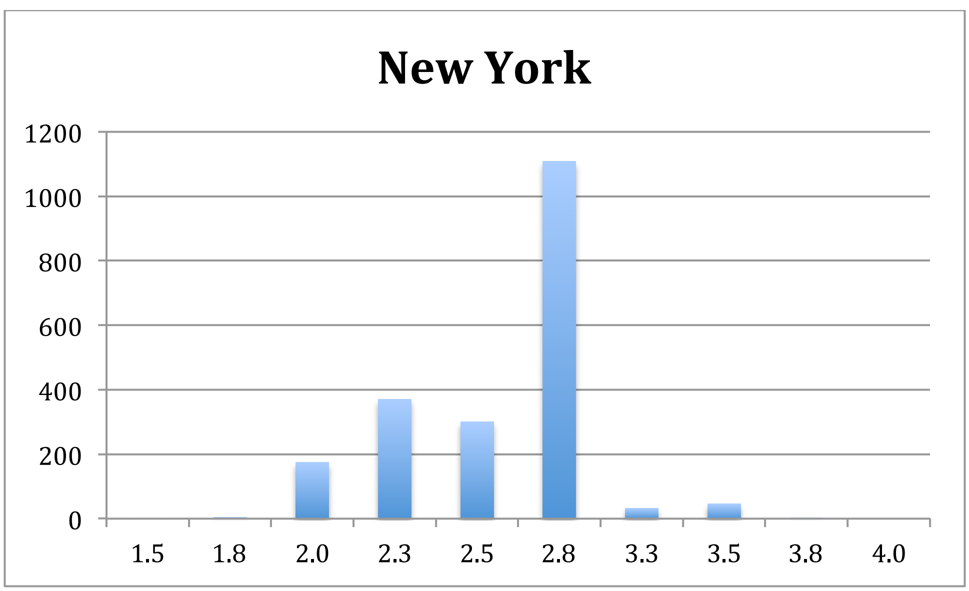

Figure 5b

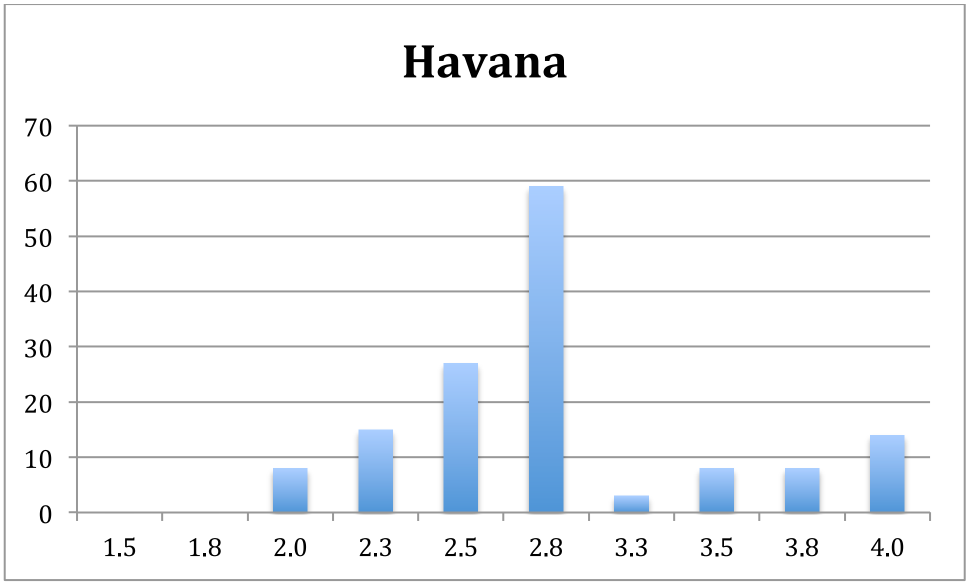

Figure 5c

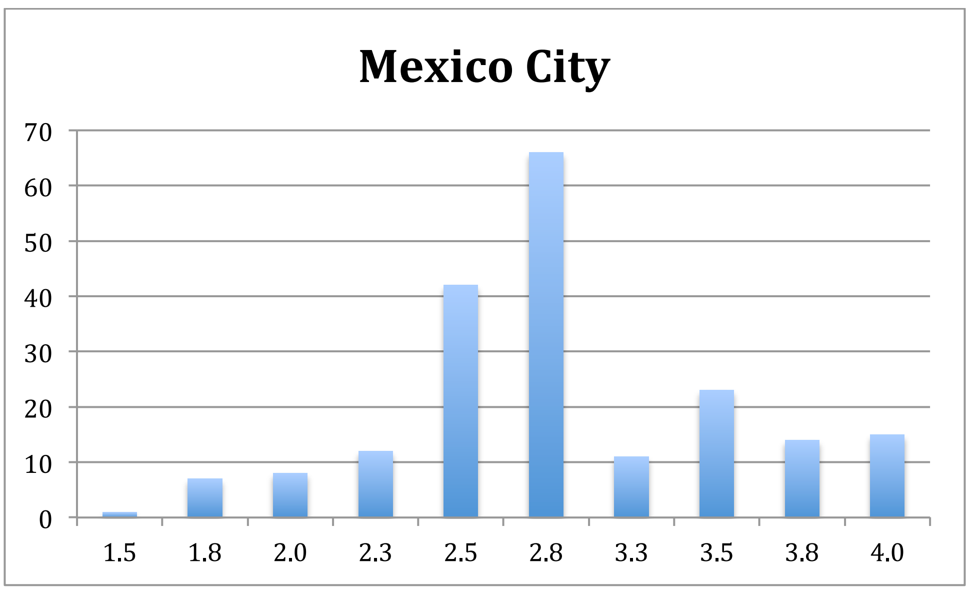

Figure 5d

In conclusion, when working with acoustic Victor discs, a 95% certainty for proper stylus size is obtained by reviewing just four stylus sizes. If this sample were random, that is if it followed the normal distribution under a bell curve, the data would be symmetrical, with an equal distribution of samples to left and right of the peak. However, there are nearly 100x more samples of smaller stylus sizes to the left of 2.8 than larger stylus sizes to the right of 2.8, indicating something is causing the non-random distribution.

Might the intended cutting stylus size have been 2.8mil? As the cutter was used, was it worn down, to a smaller and smaller size, until it was replaced?

Edison Diamond Discs

The Edison recordings are represented by 2,500 sides. Edison's company retained samples of most discs it recorded. The collection includes released discs, multiple takes from which the released version or versions were selected, as well as unreleased material. Similar in scope and condition to the Victor discs, this is an enormous collection of rarely played discs.

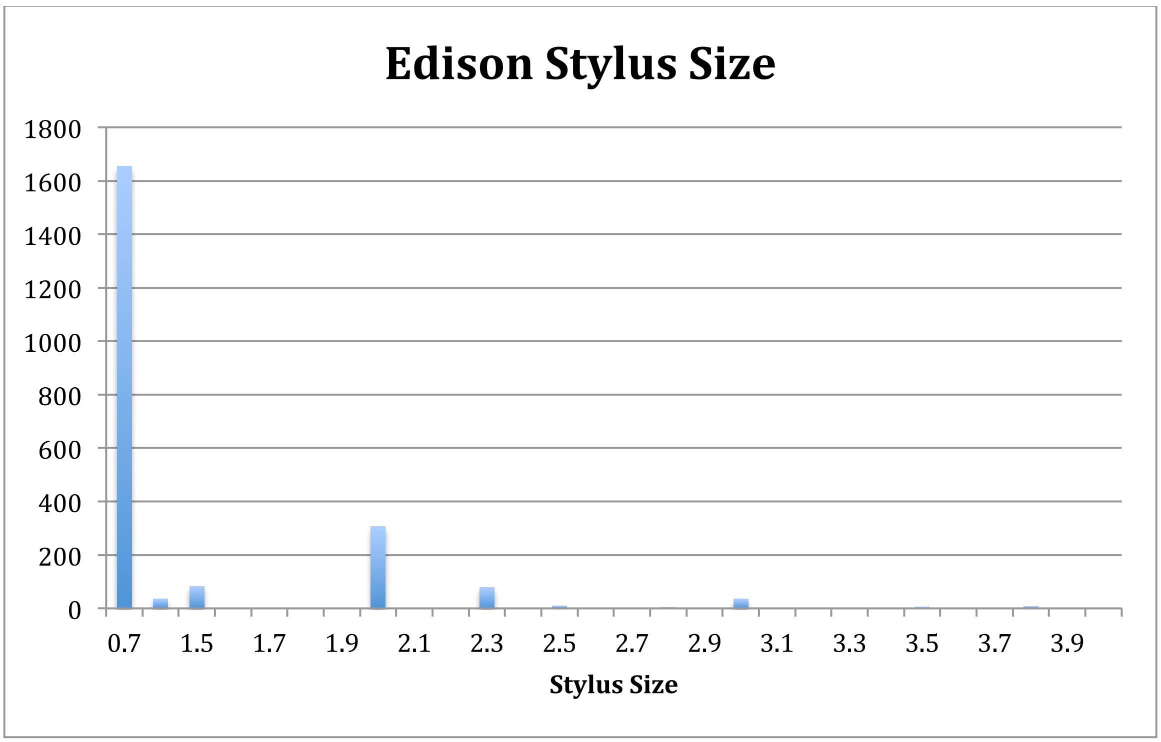

Figure 6

The results of analyzing stylus selection for Edison Diamond Discs (Figure 6) are likewise very clear. They are also very puzzling. Edison, as an engineer, was meticulous in the specifications for his inventions, their manufacture and use[12]. Engineers, collectors and historians have long struggled with a great disparity: we generally agree that Diamond Discs "sounding better",(whatever that means) when played with a very small stylus; and yet, the documentation left by Edison indicates a larger, 3.5 or 3.3 mil, stylus size should be used for playback.

[12] Cf. footnote 3.

Disc grooves are three-dimensional: top to bottom, left to right, and along their length. In practice, either the lateral (in hill and dale) or vertical (in lateral cut) component is absent[13]. Discussions of stylus shape focus on the cross-sectional view of the “stylus in the groove”; that is, how the stylus fits and tracks side-to-side or up-and-down. Less frequent are discussions that consider the relationship between the longitudinal shape and size of the cutter and that of the playback stylus. The cutter, by definition, will have a sharp point: it may be 3.5 mil across but it is shaped (ground or cut) into a sharp point to cut into the recording medium (at first wax, then later lacquer). A playback stylus that had a sharp edge, and short longitudinal profile, would naturally tend to cut the disc while being played. Shellac is much harder than wax, but the problem remains. Further, remember how these media were played: a stylus wiggled in the groove, then transferred that wiggle to a diaphragm that transduced the motion into varying air pressure (a.k.a. sound) which was amplified by a horn - the larger the horn, the greater the amplification. The stylus both reproduced the sound in the groove, and moved the horn apparatus across the disc[14]. To keep the stylus in the groove firmly enough to move the horn, a great deal of pressure was needed. The nominal weight of the diaphragm and the suspended horn is 4-5 ounces. LP turntables track at below three grams! As the surface area of the playback stylus is reduced the weight of 4-5 ounces is spread over a smaller and smaller area. This means more weight is applied to the groove, leading to increased wear. The sharp cutting stylus incises fine detail along the groove. The fatter playback stylus, needed to carry the weight of the diaphragm and horn, cannot capture the information left behind by the cutting stylus. It spans multiple hills and is unable to reach into the dales[15].

[13] Most discs are cut by modulating the groove side-to-side (“lateral cut”). Edison media are cut up and down (“vertical cut”), a.k.a. “hill and dale”. Vertical cut discs have more consistent groove geometry. However loud sounds tend to eject the stylus from the groove. Ultimately lateral cut was used by most manufacturers, and became the standard for LPs.
[14] Edison Diamond Disc players include a feed screw to move the stylus and horn across the disc. This requires the pitch (number of turns per unit distance) of the disc and feed screw to match. Otherwise the feed screw would cause the disc to skip forward or backward.
[15] For a discussion on tracing distortion see Di Toro, J. SMPTE **29**, 493, 1937

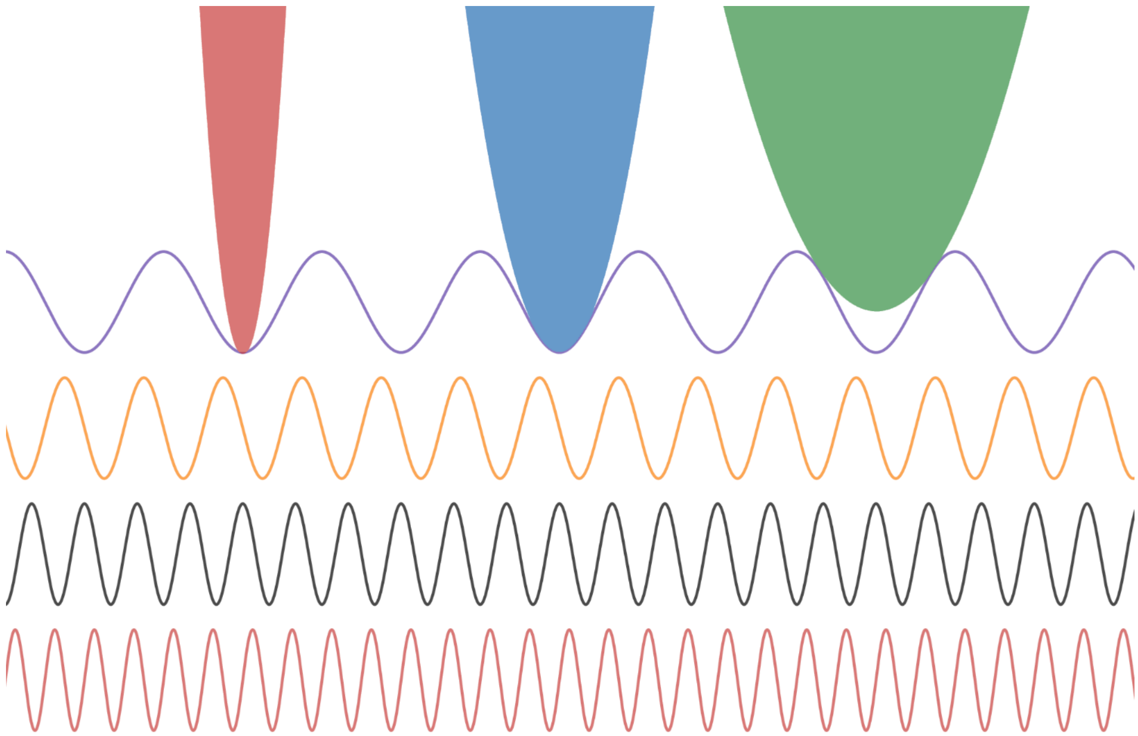

Figure 7

Higher frequencies have smaller wavelengths. Smaller wavelengths are smaller groove sizes (lower waves in the image). Large styli distribute the weight, but don't fit into the groove (right). The center stylus fits Edison's specification. The left stylus sounds better.

Might it be that Edison's working assumptions regarding the relationship between the cutting stylus size and shape[16] and the playback stylus size and shape were incorrect[17]? Instead might it be that Edison's cutting stylus, especially in the hill and dale topology, resulted in a groove profile best reproduced by a very different stylus: a size and shape not easily obtained at that time?

[16] Edison's grooved media used a geometry often called "door knob" shape, from the popular shape of Victorian era hardware. Other manufacturers used conical shape, triangular in profile, or a triangular shape with the point removed.
[17] The assumption is the playback stylus should have the same profile as the cutting stylus. This is impossible to achieve. The shape might be very, very close, but due to irregularities in the recording medium, and the replication process, as well as wear of both the cutting and playback stylus, an exact match cannot be achieved.

OKeh Records

The work on Victor and Edison discs was performed under a contract specifically intended to generate content for the Library of Congress' National Jukebox[18]. A later contract was awarded for digitization of general audiovisual holdings of the Library. The Moving Image Broadcast and Recorded Sound Division (MBRS) selected a large span of OKeh[19] Records for preservation digitization under this contract.

The samples are acoustic recordings, the earliest of which are sometimes vertically cut (like Edisons), spanning approximately a decade. Unlike the Victor and Edison discs in this study, these discs are heavily worn from general circulation and years of enjoyment by their owners. Their condition varies widely - very good to poor, and, rarely, very fine like the Victor and Edison discs. For our study these discs are a contrasting label and contrasting condition. They are from the same time period, and have been digitized using the exact methodology as the Victors and the Edisons (e.g. using four tone arms, etc).

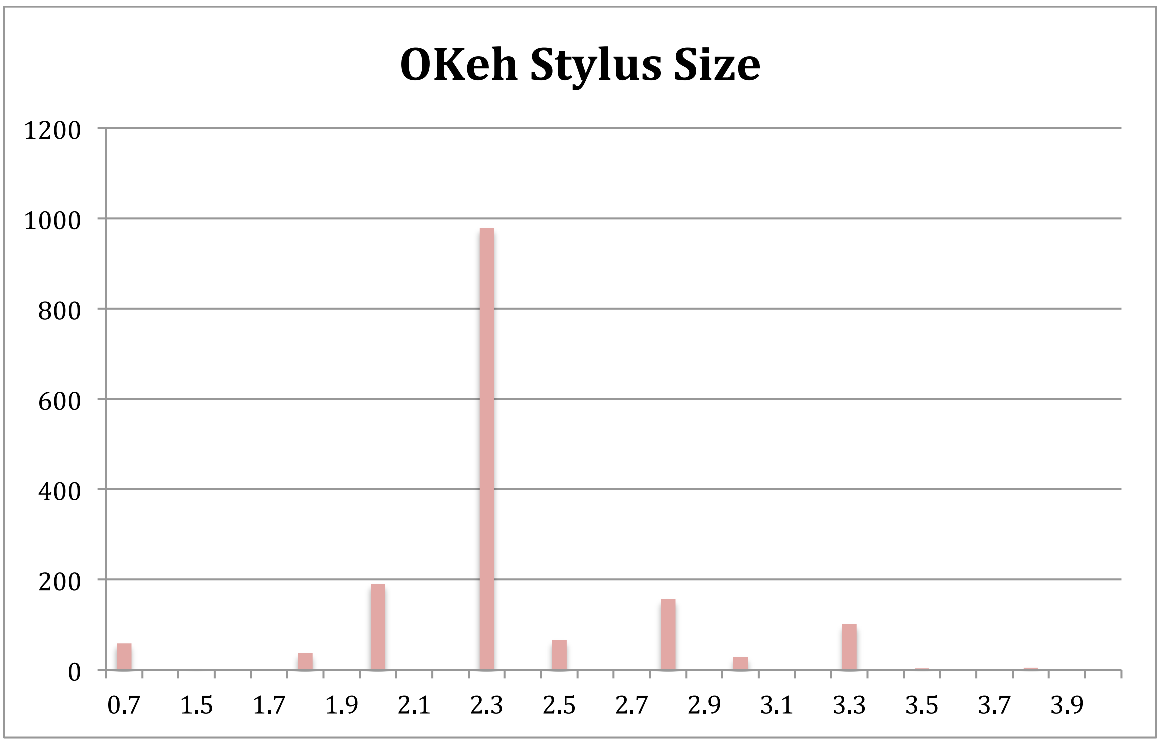

Figure 8

Whereas the Victors showed a clear preference for 2.8mil and Edisons for 0.7mil, OKeh acoustic discs have an equal preference for 2.3mil. In contrast to where the

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[18] www.loc.gov/jukebox

[19] Fun fact: At the beginning of the 20th century "OK" was a popular, new expression. While the spelling evolved to "okay" or simply "OK", at this time it was spelled "okeh". The label's name is a play on this new expression and the founder's initials Otto K.E. Heinemann.

Victors show the prominent 2.8 followed by the secondary peaks to the left of smaller sizes, the OKeh data show an even distribution to the left and right of the peak, of larger and smaller stylus sizes.

Might the engineers at OKeh have changed cutting styli more frequently than was the practice at Victor? Despite the clearly audible signs of wear and aging, the OKeh data on stylus size are among the clearest of all the data sets in this study. Might the long-held assumption in our trade, that stylus selection includes compensating for groove wear, be wrong? Could it be that usage wear does not fundamentally warrant a stylus choice different than would be made on a pristine disc?

Mick Moloney Collection of Irish-American Music and Popular Culture, New York University

The NYU/Moloney Collection focuses on genre rather than label. The playback stylus size selection for the discs shown in Figure 9 is included to represent the distribution of stylus sizes in the general population of discs available throughout the 78rpm era.

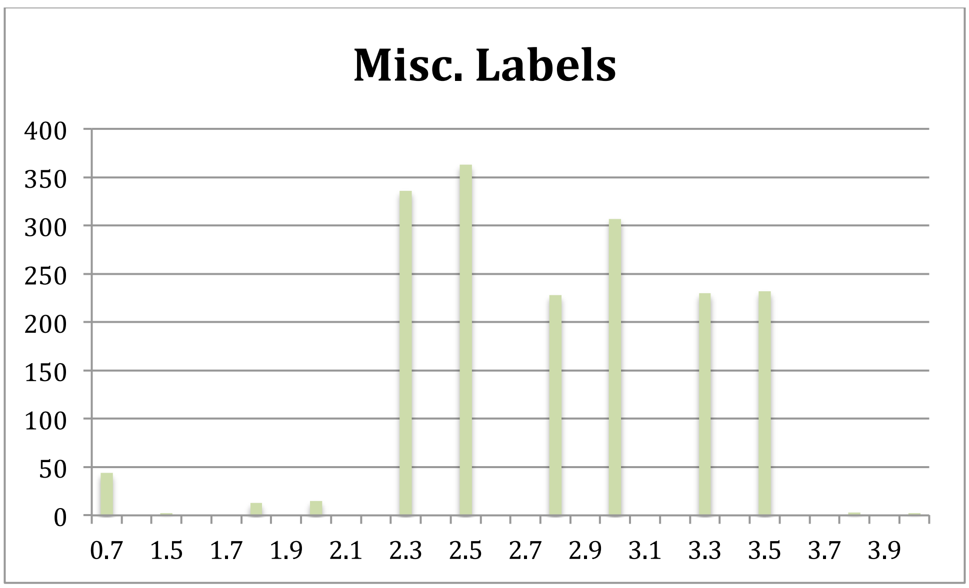

Figure 9

This data affirms that the single engineer who digitized all four sets (Victor, Edison, OKeh and Moloney discs) was thorough and considered multiple stylus sizes during his selection process. The chart also shows a distribution clearly different from those from the label-specific data, where there is a clear preference for one size over all others. Here we see, in a random selection of labels, no clear choice of stylus size is evident.

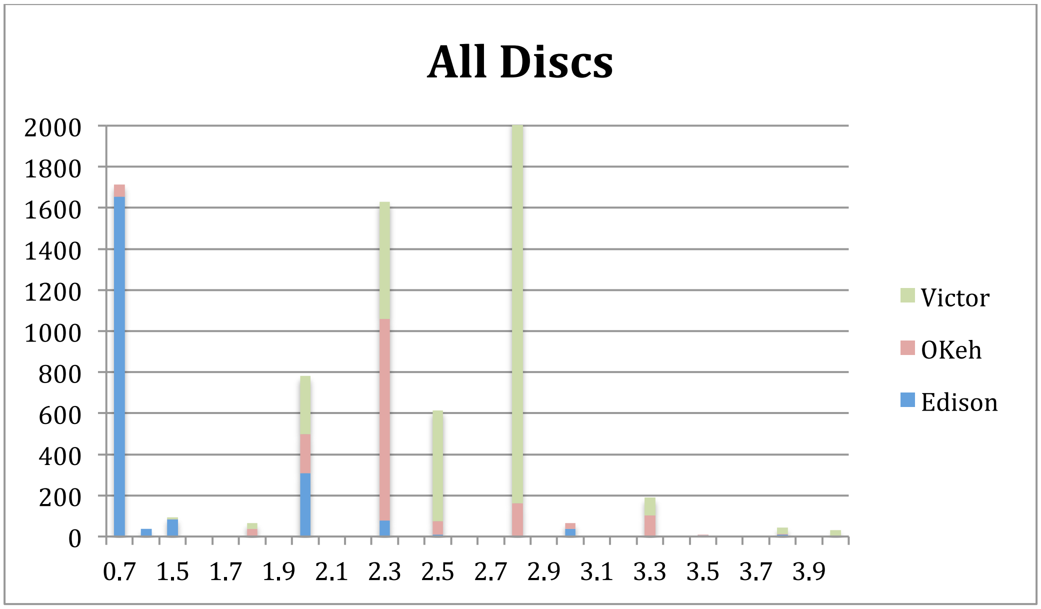

Figure 10

The chart in Figure 10 combines all the data from Victor, Edison and OKeh. Both show many strong peaks and no clear preference, supporting the assertion the NYU/Moloney collection is representative of the general population, and the label specific data is clearly different from the general population. The peaks do not match because the underlying labels are different. The goal is not to say the two charts match. It is to show that when multiple labels are present in the data there are multiple peaks. When a single label is examined in large quantities, a clear preference emerges.

One final data set for stylus selection…

Marcos Sueiro Bal Double Blind Study on Stylus Selection

At the 2015 International Association of Sound and Audiovisual Archives (IASA) Conference in Paris Marcos Sueiro Bal, Senior Archivist at WNYC in New York and co-chair of the Association for Recorded Sound Collections (ARSC) Technical Committee, presented preliminary results of his study on stylus selection. Sueiro Bal made short digital files of disc transfers. Each disc (presented below in its own chart, Figures 11a-11e) is a different genre. Each disc was played multiple times, each time with a different stylus size and shape (A-E or A-F in the following examples). There were 5 or 6 stylus sizes for each of 5 different musical genres in preparation for a double blind test, he asked a colleague to rename the samples to obscure information about the styli used for playback of the samples. Sueiro Bal asked respected audio transfer engineers to review the files at their leisure using their preferred playback environment, and to report their preferences. Two

respondents[20] took the test twice. The responses provided 49 data points for each musical selection.
The assumption has been that an experienced engineer with training on what to listen for is needed to choose the proper stylus size; yet, only one test shows a consensus preference.

The results of the tests are presented in the Figures 11a-11f.

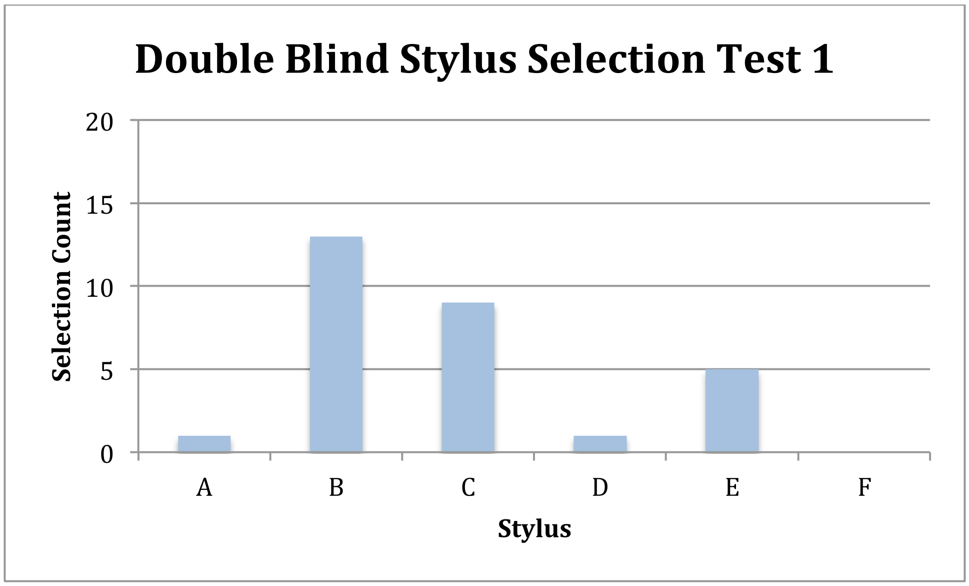

Figure 11a

[20] Marcos Sueiro Bal himself and George Blood, the author of this paper.

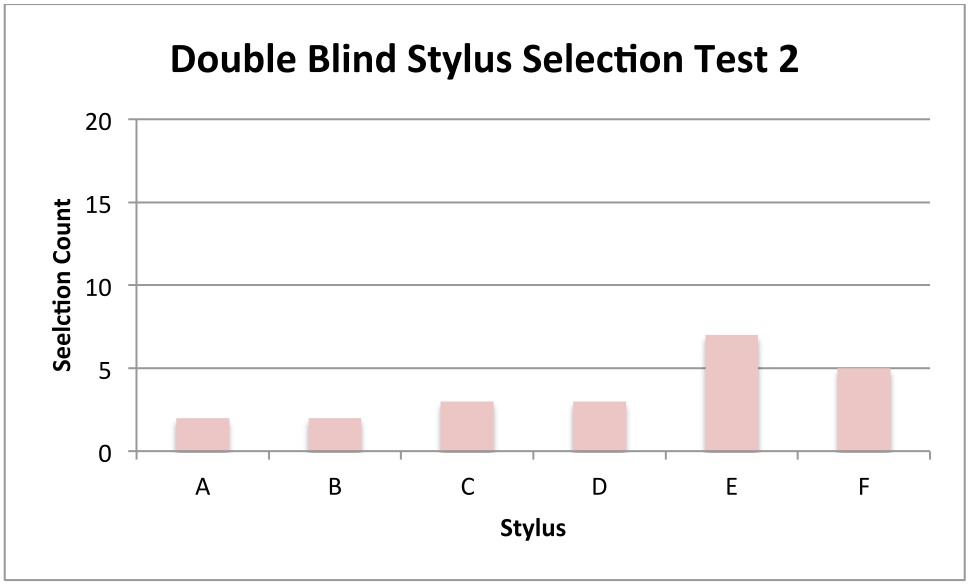

Figure 11b

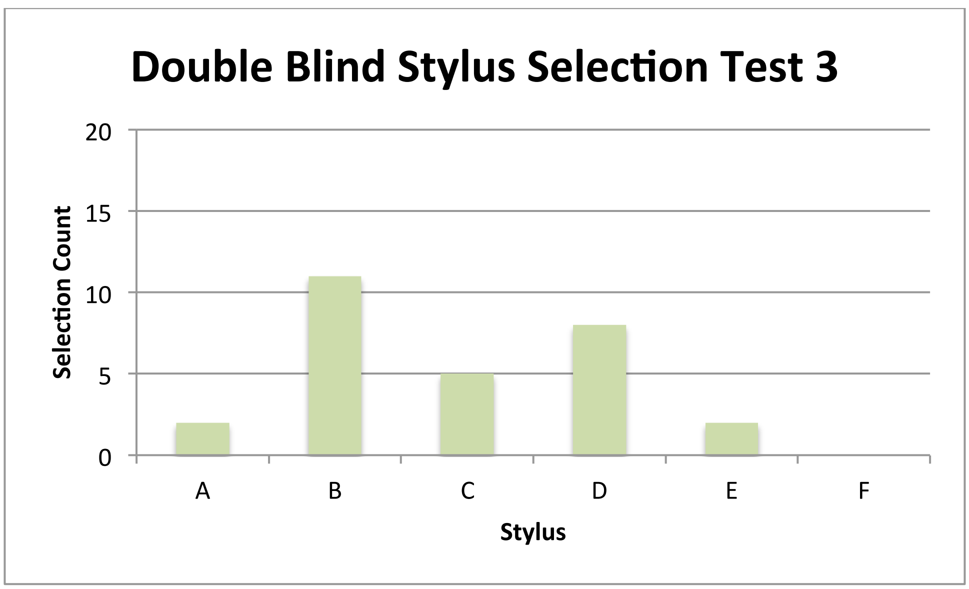

Figure 11c

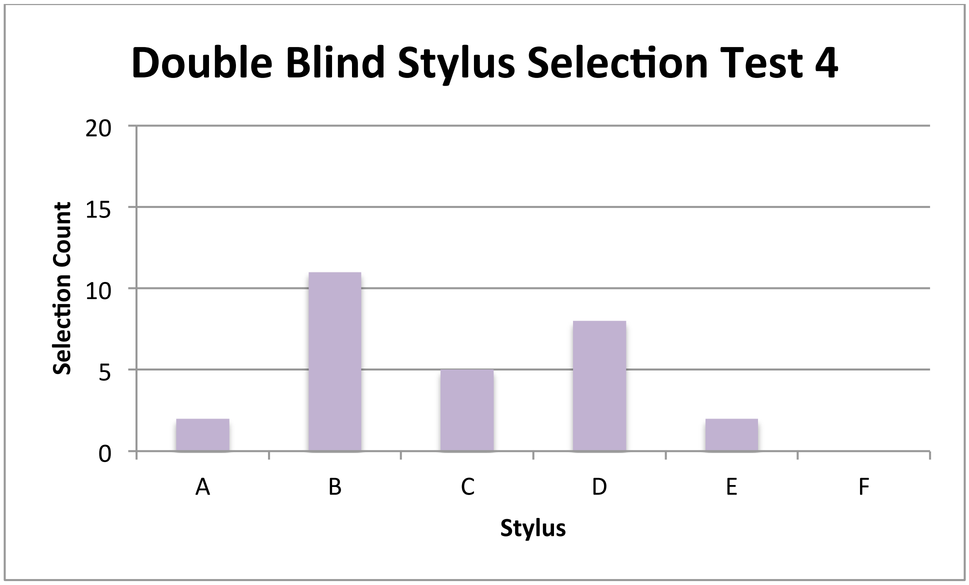

Figure 11d

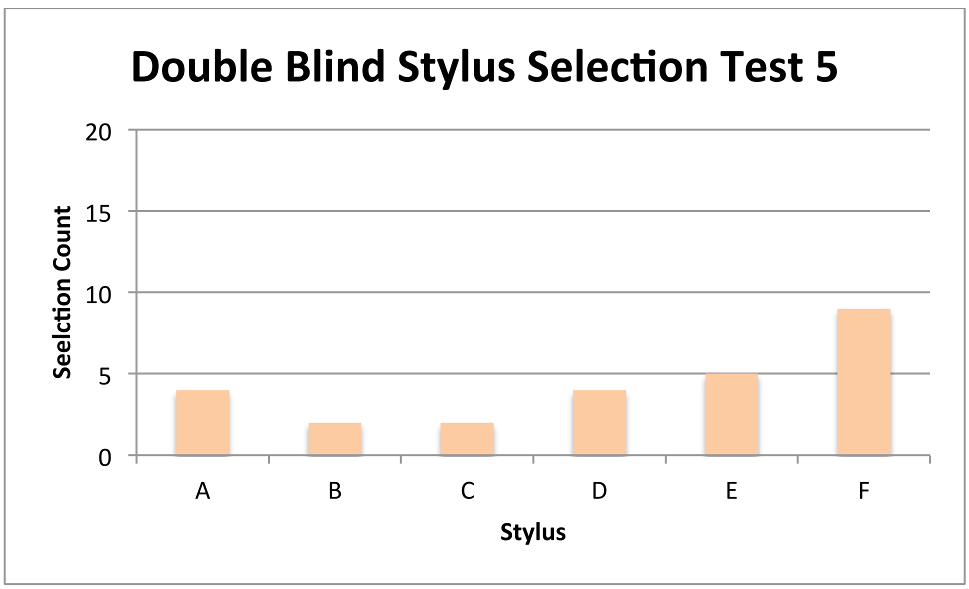

Figure 11e

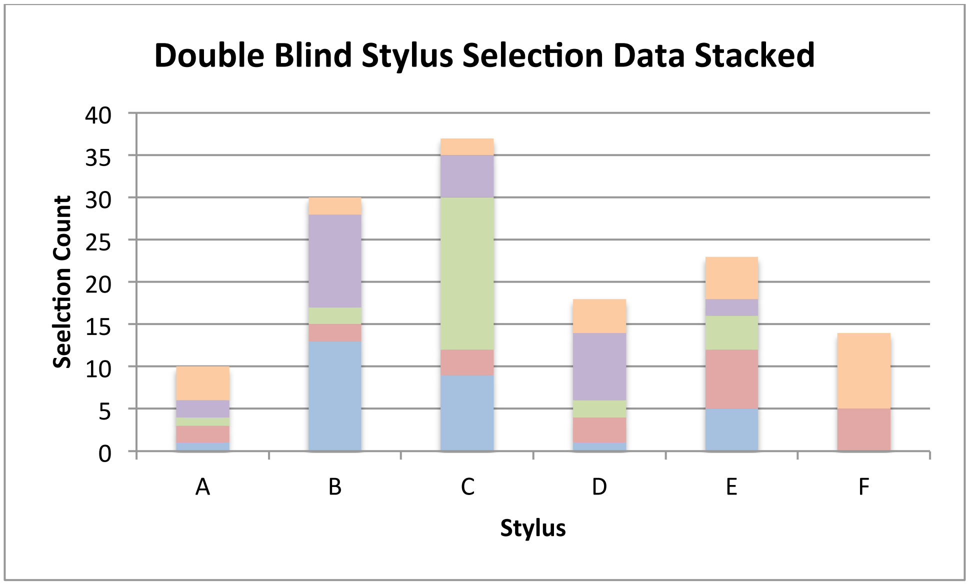

Figure 11f

The last chart, Figure 11f, includes all the data points for all five tests together.

There is no distinct preference for any given ordinal choice; that is, there is not a bias toward choosing the first item heard, for instance. From this distribution it appears the engineers taking the test took their time to carefully consider all the alternatives.

The wide range of results for each sample calls into doubt whether we can assert that the choices of stylus size, even by professionals, results in the "best", "proper" or "correct" stylus. This doubt is reinforced by both respondents who took the test twice and gave different preferences in most instances.

Summary Conclusions on Stylus Size Selection

• The proper stylus for a given label in a given era can be known with high certainty.

- Victor: 2.8mil is the best stylus size. In practice 2.0, 2.3 and 2.5mil sizes are needed
due to apparent wear in the cutting stylus on some recordings.

- Edison: 0.7mil is the best stylus size.

- OKeh: 2.0 is the best stylus size.

- NYU/Moloney: aggregate data demonstrates a wide range of practice during the period before 1923.

• Wear may not affect stylus choice after all.

• Stylus selection by experienced and respected engineers is highly variable and not repeatable according to the generally accepted standards of the scientific method.

PART 2, SPEED DETERMINATION

While pitch and speed are inextricably linked, they will vary independently of each other during recording. Just as two disc cutters might operate at a different speed, two artists performing to the same lathe might tune to a different pitch. During playback however, without additional information, it is not possible to separate the two effects. The result might be due to the cutting speed, or the tuning pitch, or a combination of both. Pitch A might be 435Hz or 440Hz. Rotational speed might be 71.29rpm or 78.26rpm. However, if A=440Hz=78.26rpm, then A=435Hz ≠ 71.29rpm.

As discussed in the introduction, speed determination of recordings from the early 20th century is challenging due to widely varying practices for reference pitch, difficulty controlling mechanical speed of the recording lathe and playback turntable, lack of documentation, and other technical and cultural factors[21].

- Parameters are moving targets.
  - A=?
  - How fast does a turntable spin?
  - How do you control that speed?
  - Regional differences in pitch and/or recording practice
  - Ambient temperature changes pitch of the instrument between takes
  - A work is otherwise too long to fit on one side
  - Simply playing out of tune (or different temperament)
  - Ego/Ability (want to appear to sing higher or play more "brilliantly")
  - Who cares?
  - Operator error (during recording or playback)

As demonstrated for stylus size in the example of the NYU Moloney Collection, our control group, it is possible the apparent randomness could be the result of many different variables laid on top of each other. That is, if the data is parsed into its component subsets, discrete causes might emerge.

[21] Other factors may introduce variation or noise into the data. These include digitization engineer choicing up or down to the nearest semitone, discs whose speed varies across the duration of the disc, wow and flutter, non-equal tempered tunings, etc. Each of these may impose additional considerations upon a given side. However, their frequency of occurrence is low, and therefore only noise in the data, not influencing the conclusions. Cf. the discussion and charts that follow.

Or they may not. Recall that the distribution of stylus sizes for the Victor discs did not vary over time or by location.

In the traditional method for pitch detection the engineer matches an external pitch, whether it be from a tuning fork, pitch pipe or other source, such as a small keyboard[22].

Pitch detection for the work in this study used a polychromatic tuner[23]. This measures all 12 pitches, in real time, at the same time. Pitch is set very rapidly, very precisely and with high repeatability. This is a significant advance over traditional methods.

For this project, the clients, the Library of Congress and New York University, specified that the *speed* of the discs be varied such that A=440. Noting that discussion of the merits of that choice are beyond the scope of this paper, the author wishes only to point out that the choice is highly defensible and, for this study, the key to producing meaningful data on speed and pitch selection during the acoustic era. Because, if playback is to be subject to "what I like best", then the data will vary just as it did in Marcos Sueiro Bal's study on stylus selection. There would be no anchor around which to compare the results.

With the target fixed, investigation of variance from that target is possible. The same would be true if the target were A=435Hz or rpm=78.26 or 77.92. The locus of the data changes, but the variation and distribution around the reference does not.

The charts are plotted with percentage deviation from A=440Hz on the vertical axis (+/- 9.9%), and the number of samples at each 0.1% increment along the horizontal axis.

[22] A few practitioners have perfect pitch. Some choose to leave the discs at 78.26rpm and avoid this topic entirely. Others choose what they like best based on their musical judgment, and may take into consideration a pitch detection method.
[23] PitchLab is available for iPhone iOS and Android smart phones. Rare 12-pitch Stroboconn and Petersen tuners, no longer manufactured, are also suitable for this work.

Victor Talking Machine Company

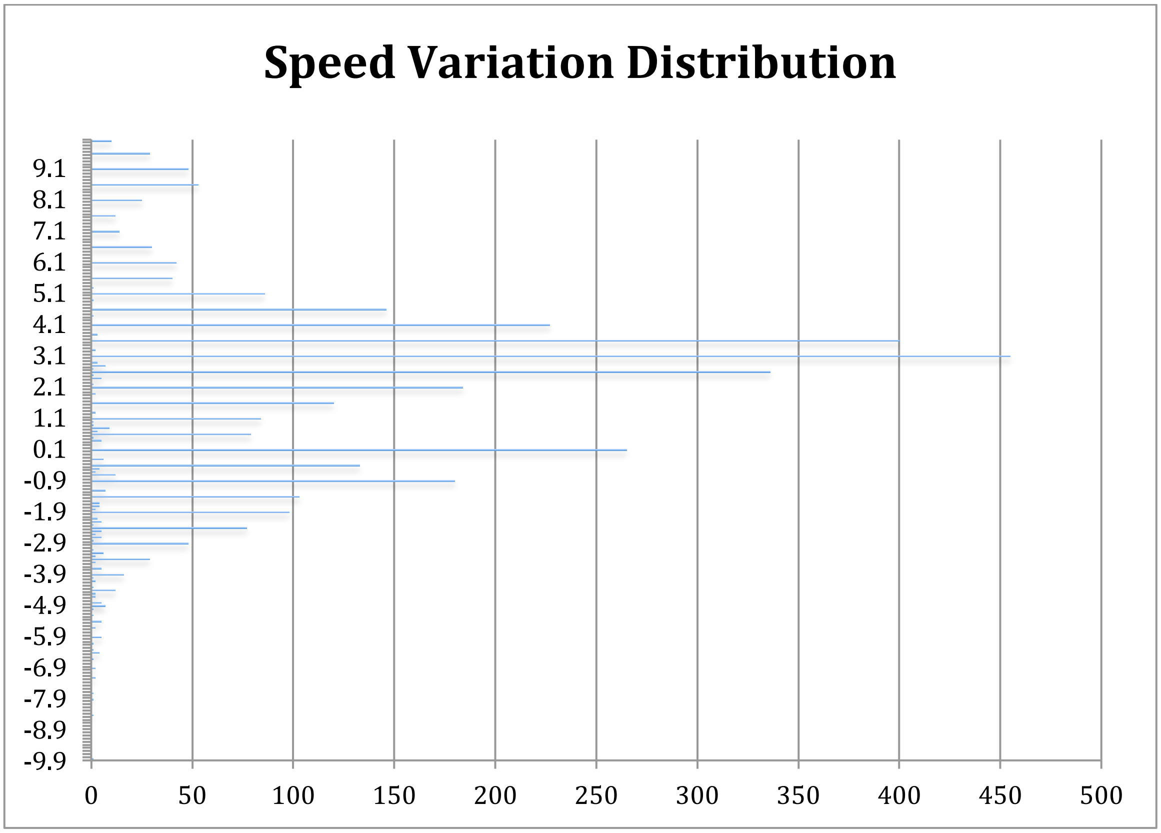

Figure 12

This result on speed variation in the Victor discs is the exact opposite of the distribution found in the stylus sizes. Where the stylus data show cleared peaks, these data are random. They follow normal distribution – also known as a bell curve – as predicted by the central limit theorem.

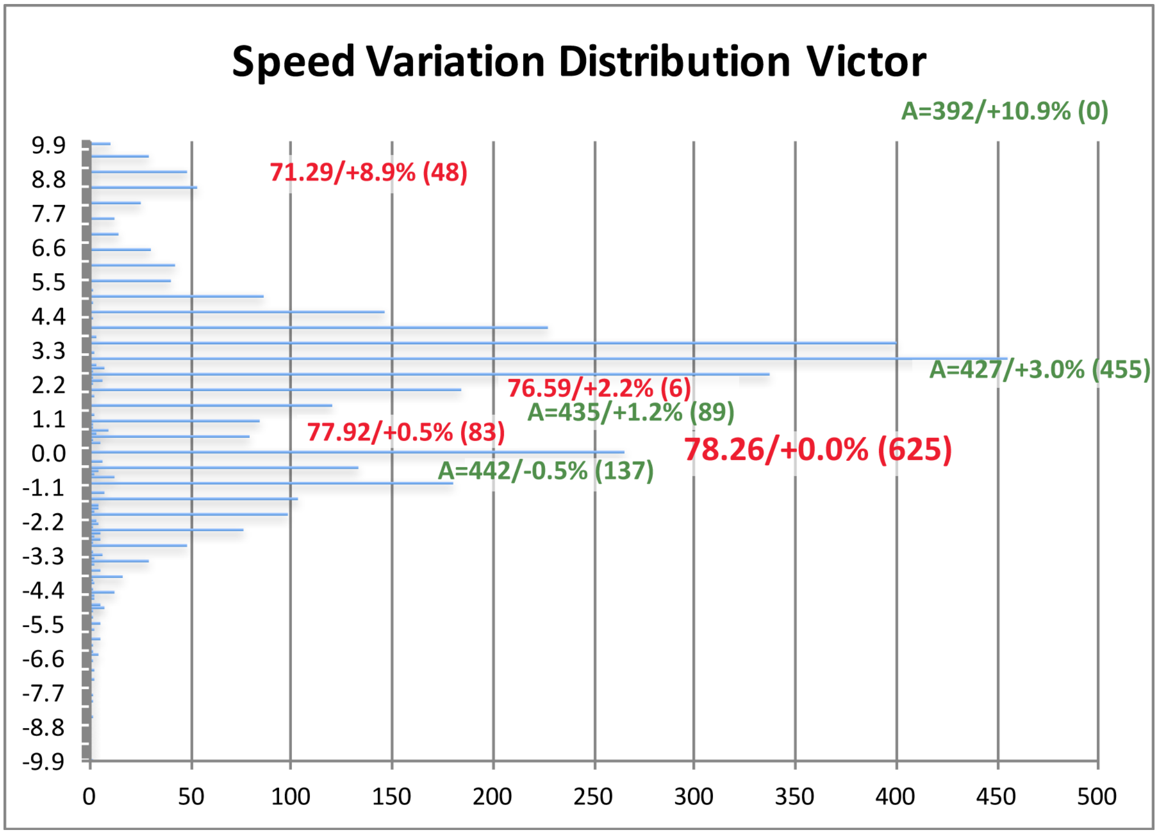

Figure 13

Since many of the recordings in this data set were made in remote locations under difficult circumstances, we can assume more chances for variation in the Victor recordings. However, as shown below, this distribution is found in all four data sets.

The historical record includes information on pitch over time and by location. The literature is full of information purporting to establish rotational speed as well. If either of these were true, we anticipate peaks in the data. Anticipated peaks include historical pitches, such as frequencies A=415, 430, 435, as well as 440, and proposed target rpm speeds such as 71.29 and 77.92.

However, when the graph is annotated with these values where we *anticipate* peaks, we instead find areas of *low* sample count. Where there are peaks in the data they do not correspond to the speed and pitch values proposed by other authors and the historical record on pitch.

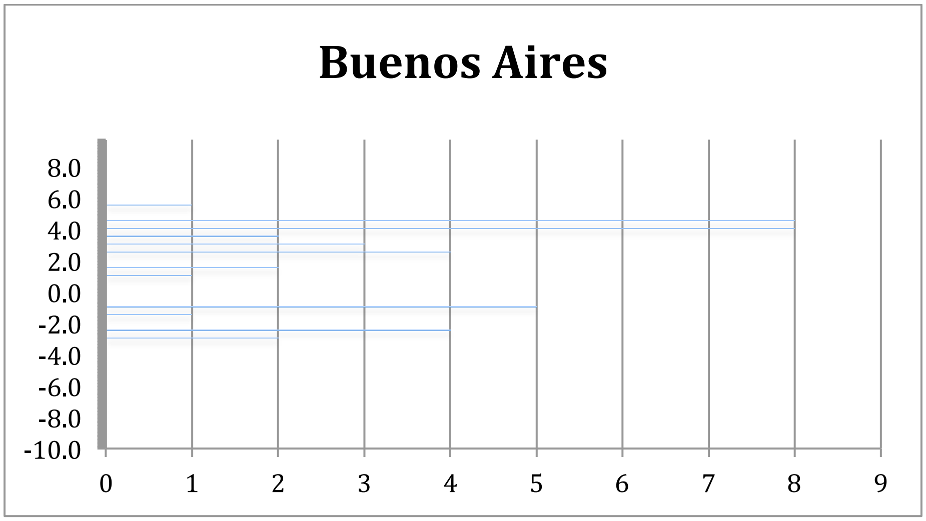

Figure 14a

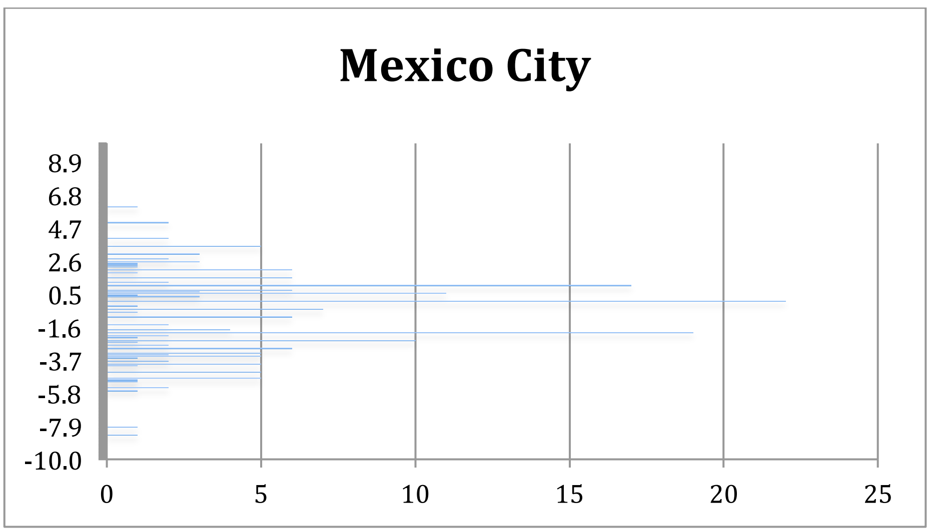

Figure 14b

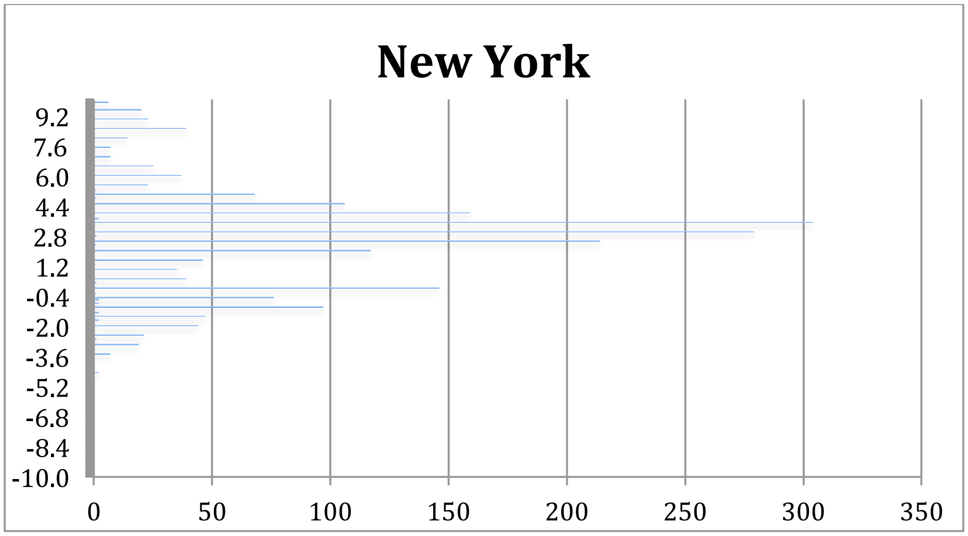

Figure 14c

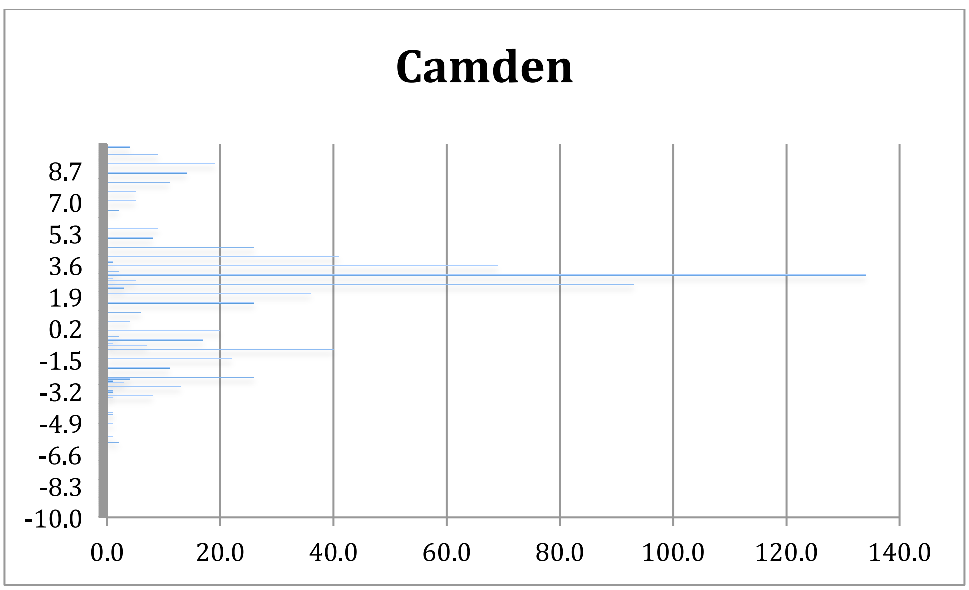

Figure 14d

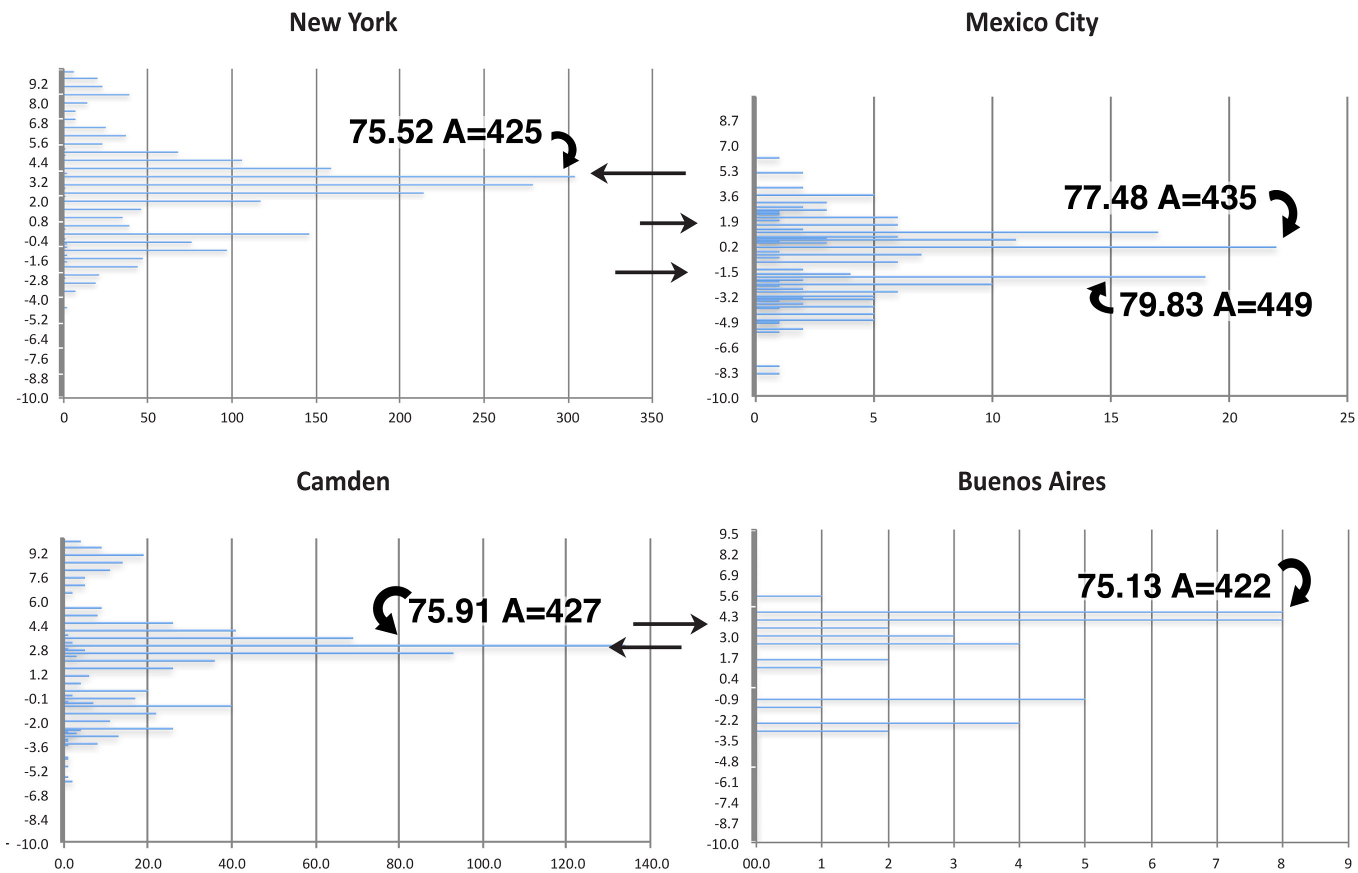

Figure 14e

The Victor data were also analyzed by recording location.

The arrows in Figure 14e highlight where the charts appear to indicate some dominance.

Here again we find the data peaks do not correspond to any anticipated pitch or speed values, with the exception of one peak in the Mexico City (Figure 14b) data for A=435, or 17 out of the 3,500 sample points. This is not statistically significant.

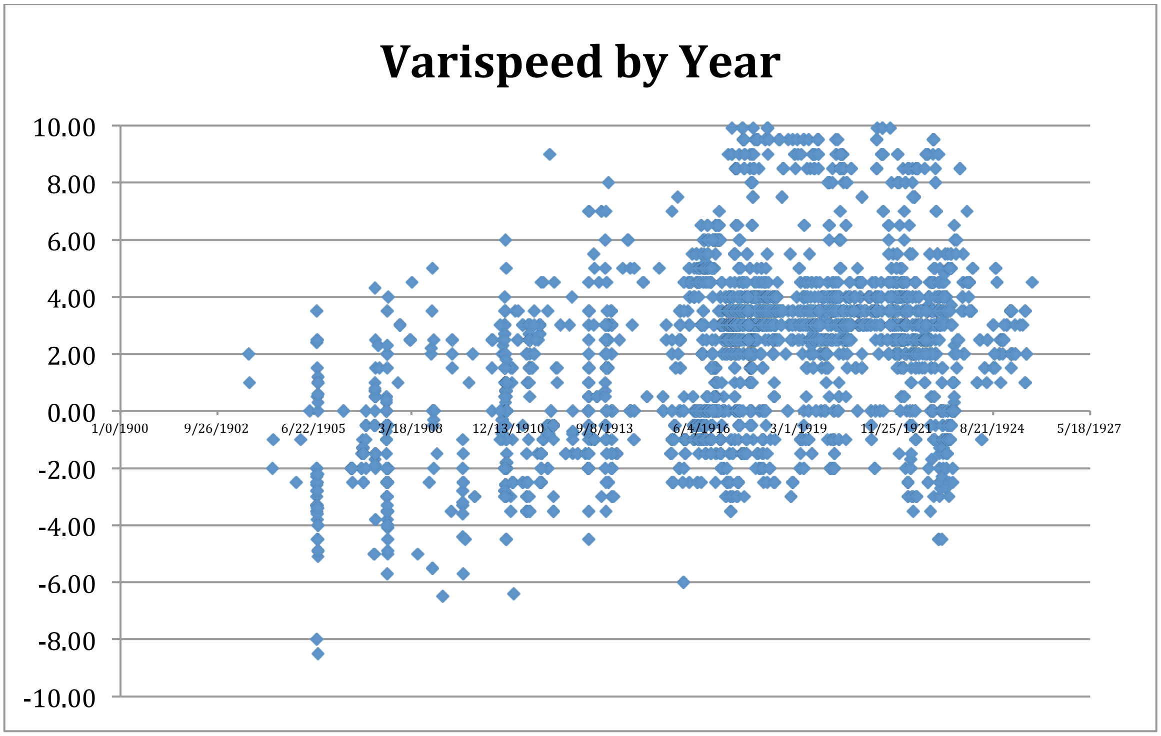

Figure 15

This scatter plot (Figure 15) distributes the data by catalog number. It clearly demonstrates a very wide dispersion in each of the subsets of the catalog periods represented in the data.

The data does show a general slowing of the record speed over approximately 20 years, in that the amount of speed correction necessary to bring the discs to A=440 increases. Slowing the discs allows longer works to be recorded.

An alternative explanation for this trend is that the reference pitch falls over this period. Since the historical record on pitch is an upward trend, this alternative explanation seems unlikely.

Edison Diamond Discs

The Library of Congress contract that specified the Victors be *pitched* to A=440Hz also specified the Edison Diamond Discs be *speed* adjusted to 80rpm. This speed selection is based on strong documentary evidence found in their corporate archives.

This work on pitch discovery was performed only near the end of the job with the specific goal of gathering data for this study, rather than as required by the contract. There are only

218 data points. An additional 2,200 sides will be digitized, and the data will be gathered and analyzed in the same manner[24].

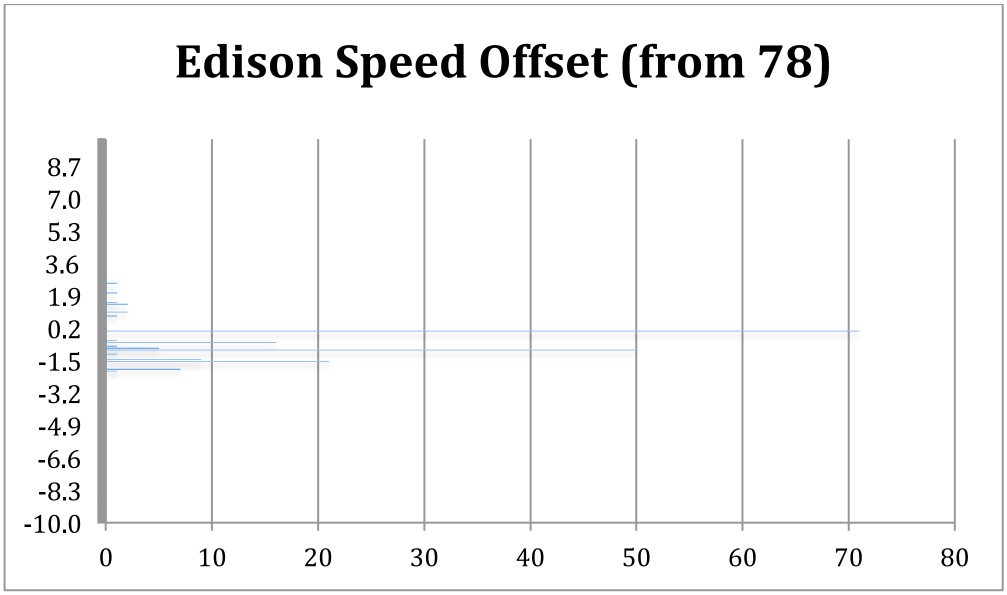

Figure 16

These early data show some interesting peaks that correspond to anecdotal information from other engineers that they often find Diamond Discs to fall not at 80 rpm, but at 78.26 or 79.04rpm.

This data is highly inconclusive.

OKeh Records

Speed variation (Figure 16) in the OKeh discs is also a random distribution.

[24] The work on additional Edison Diamond Discs will take place after the publishing deadline.

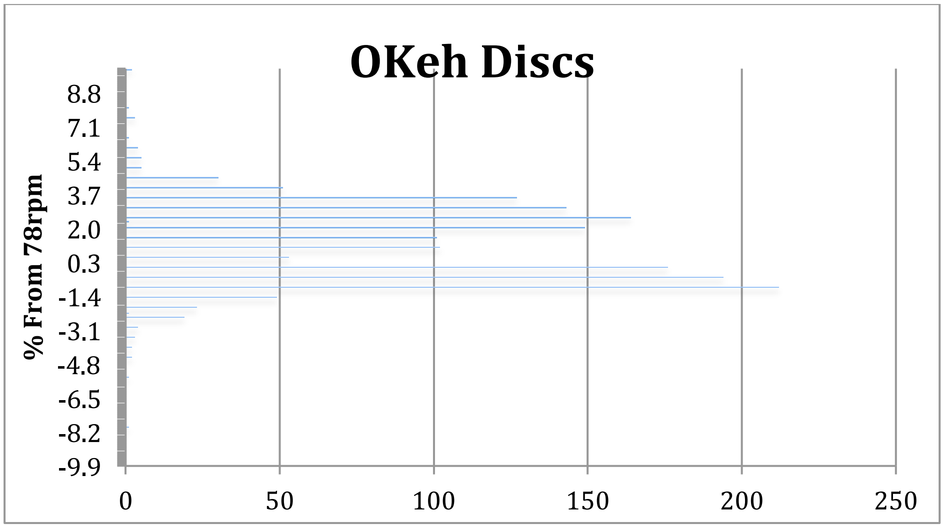

Figure 17

Mick Moloney Collection of Irish-American Music and Popular Culture, New York University

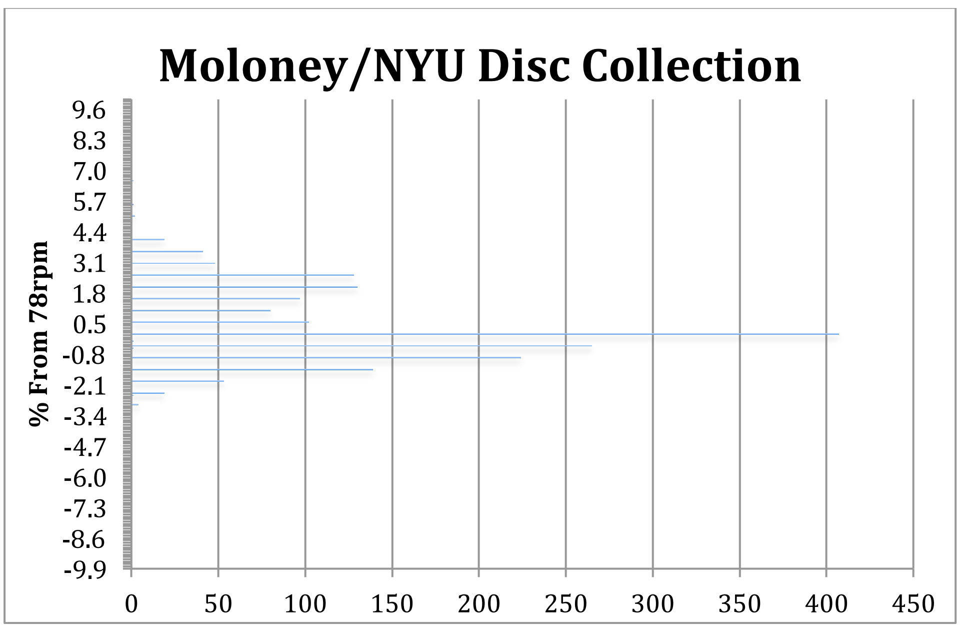

Figure 18

The data drawn from the random labels in the NYU/Moloney Collection spans a larger time period than the other data sets, extending well into the electrical era.

Might these data indicate a convergence toward 78.26 as the actual target speed of discs? Afterall, many of the challenges faced in the acoustic era working with purely mechanical systems, were either solved or improved over time with the regular use of reliable and accurate electric motors and standard line frequencies of 50Hz and 60Hz.

Additional Information on Speed Determination

We embrace that 78.26rpm may not equal A=440Hz, but we want it to equal something. However, might we be imposing our early 21st century expectations on a late 19th century culture? Consider the following three anecdotes.

First: Attendees of the 2011 IASA Conference in Frankfurt were treated to a performance by the Sixtonics. The concert included a live recording demonstration using restored early electrical recording equipment. When the resulting lacquer disc was played back, one of the musicians asked why it played at a pitch higher than they had just performed? The drag of the cutting stylus had slowed down the lathe during recording. When the disc was played back there was less resistance and the turntable played up to speed.

- What is the proper way to play back this disc? At the originally performed pitch, or the pitch that would have been experienced in the home?
- Do we assume it took 100 years for someone to notice this phenomenon? Or is it merely the case that 100 years ago pitch varied so widely it was taken for granted?
- Might the 79.04 speed observed in the small Edison sample correspond to this demonstration?

Second: In 2011 your author recorded all 14 Bach keyboard concerti on a collection of restored antique harpsichords. The instruments were built between 1627 and 1707. When the instruments were built, pitch was trending from A=392 to 415. During restoration each instrument was pitched differently according to the tradition of when and where it was originally made. To avoid strain on the instruments, and many broken strings during the recording, all the instruments were retuned to a compromise pitch of A=400, a pitch with no historical foundation whatsoever. Other recordings have been made with these instruments in solo or continuo roles. In those recordings, made in the span of a few years, the instruments were tuned to their native pitches: 392, 405, 407, 410 and 415. If these had been among the Victor, OKeh and Moloney discs in this study pitched to A=440, every one would be mis-represented, and each in a different way.

To anyone who presumes to know exactly the correct pitch to play any given acoustic era disc, we offer the following YouTube video.

- https://www.youtube.com/watch?v=UnhlQUBsd6g

Summary Conclusions on Speed Determination

• Analysis of 4 data sets totaling 9,000 sides, of pristine discs, worn discs and a random selection of labels, demonstrates no clear pattern to definitively determine the speed or pitch of acoustic era 78rpm recordings.

These findings inform the process of preservation. It is necessary to use the proper stylus because it is not possible for the listener to alter that choice. Speed, on the other hand, can be changed when playing a digital file. In practice it may make sense to choose a fixed reference (speed or pitch) for playback and leave it to the user to decide; and to provide multiple playbacks with different styli, and again leave it to users to chose which they prefer.

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